LASER AND PLASMA INTERACTION AT HIGH POWER LASER FLUX

A SYNOPSIS OF THE PROPOSED WORK TO BE CARRIED OUT
IN PURSUANCE OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE

OF

DOCTOR OF PHILOSOPHY

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INTRODUCTION:

Plasma is a quasi neutral gas of charged and neutral particles which exhibit collective behavior. In collective behavior, motion depends not only on local conditions but on the state of plasma in the remote regions as well. Plasma often behaves as if it has its own mind. Quasi neutral indicates that it is neutral enough so that one can take $n_i \approx n_e \approx n$ where n is common density of charge particles called as plasma density, but not so neutral that all the interesting electromagnetic forces vanish. Plasma provides non linear, breakdown free medium to generate Tera Hertz (THz) radiations. THz frequency lies between the microwave and infrared regions of the spectrum. Its frequency is in the range of 300 GHz to 20 THz. One Tera hertz frequency has, Wavelength 0.3 mm, Photon energy 4.14 m eV, and Temperature 48 K

Properties and applications of THz [1,2]

1. **Chemical and security identification**: As it can penetrate non conducting material (dielectrics) as cloth, plastic, cardboard etc but cannot penetrate through water, liquid, metal, THz can be used in surveillance to detect weapons, explosives, drugs etc.
2. **Biological imaging:** As THz is non ionizing, with low photon energy, tissues and DNA do not get damaged. Hence it is useful in detecting epithelial cancer as these radiations can detect difference in water content and density of a tissue, it is better than X-Ray in 3D image of teeth.
3. **Remote sensing:** It has line of sight propagation but strongly absorbed by atmosphere, so can be useful for high altitude communication like aircraft to satellite, satellite to satellite etc.

Generation techniques of THz radiations :

There are several ways to generate terahertz radiation: some methods involve interaction of short laser pulse and energetic electron beam with plasma. Plasma is used as a medium because it can provide a very high dipole moment [3] and can easily handle very high power radiations. In several experiments plasma is employed as a nonlinear medium for the THz generation.

Huge peak power of Tera Hertz radiation (Giga watt) can be obtained by:

- a) Self induction: It is due to the field of ionizing laser pulse itself, excites THz current in plasma.

  b) Forced generation: It is due to pumping of static or microwave electric field or the field of second harmonics of a laser pulse [4].

- THz may be generated by
  1. Optical rectification
  2. Difference frequency generation (DFG)
  3. Parametric generation.

  One needs a femto second laser pulse for optical rectification whereas nano second laser pulse or continuous wave (cw)-laser for the remaining two. These are second order non linear processes which occur in non-centrosymmetric materials. DFG has high conversion efficiency and needs two collinear phase matched laser beams [2].

- Strong THz radiations emit when optical pulse with group velocity greater than phase velocity of terahertz is focused in non linear medium, transparent to THz radiation. For example if ZnSe, GaSe, ZnTe the large band gap semiconductors are periodically biased or using electro optic crystals for optical rectification.

  Although GaAs used as the photoconductive antennas act as emitter as well as receiver of ultra broadband THz. (Emission of 15 THz and reception of 30 THz)[5].

But due to damage limit and conversion efficiency of these materials it is difficult to obtain powerful THz emission.

- Static electric and magnetic field in plasma enhances THz generation. In presence of axial density gradient a laser pulse excites large amplitude plasma wake field with plasma frequency. The efficiency of THz so generated increases remarkably in presence of transverse magnetic field, the intensity of THz is proportional to magnetic field strength. The Ponderomotive force of laser pulse generates phase matched THz radiation by the use of corrugated plasma channel [6].

Laser plasma interaction:

When laser propagates through plasma it imparts large oscillatory velocity to electrons which couples modes of plasma and can grow with time. Intense laser can couple nonlinearity to weakly damped electrostatic waves in plasma.

The electron plasma wave (EPW) and ion acoustic wave (IAW) are two small amplitude plasma modes in unmagnetised plasma. Non linear coupling of these modes can result in enormous loss of energy via stimulated Raman scattering (SRS) [7] in EPW and stimulated brillouin scattering (SBS) [8] in IAW, in these forms laser light gets scattered hence reduce the coupling efficiency between laser and plasma.

The non linear processes in laser plasma coupling depend on laser parameters, like intensity, wavelength and plasma parameters like density, temperature and inhomogeneity which affect coupling efficiency. The parametric instabilities can degrade the coupling of laser to plasma, which in turn affect efficiency and location of laser absorption.

Filamentation:

Filamentation [9] is basically redistribution of plasma/ laser intensity redistribution which occurs because of the inverse relationship between intensity of laser with plasma frequency (density), larger intensity of laser creates plasma density depression. The refractive index also depends on linear as well as non linear component of laser intensity as $\eta = \eta_0 + \eta_2 E^2$. The non

linearity in the refractive index causes self focusing [10] and hence filamentation. Weak perturbation on the laser wave front perpendicular to propagation of laser initiates filamentation. The region of higher intensity has stronger Ponderomotive force that reduces plasma density further enhances laser energy in such regions causing higher fluctuations. It results the beam to break into parallel filaments of higher intensity of light or lower density of plasma. Laser beam filamentation can be suppressed by either reducing the intensity of incident laser beam or by using a beam with extremely uniform wave front. In this way the intensity of light transmitted through the given medium increases.

Filamentation in plasma can occur due to three mechanisms :

1. Thermal 2. Ponderomotive 3. Relativistic.

Thermal filamentation [11] occurs because of collisionally heated plasma, exposed to electromagnetic radiation. Hydrodynamic expansion, due to rise in temperature leads to density perturbation and causes increase in refractive index. This mechanism is not significant in plasma.

Ponderomotive filamentation[12] is caused by the Ponderomotive force, arising due to nonuniform irradiance of Laser beam expelling electrons from the region of high electric field. Non-relativistic dielectric constant of plasma, $\varepsilon_0 = 1 - \omega_p^2 / \omega_o^2$ (where $\omega_p^2 = 4\pi n_0 e^2 / m$, n_0 being the plasma electron density and ω_0 is the frequency of the laser pulse), is maximum on the axis and decreases away from it i.e. electron density is minimum on the axis. Such dielectric profile has effect on refractive index profile which changes the phase velocity of the different parts of the wave front inducing focusing effect on the channel.

Relativistic filamentation[13] The relativistic mass variation of electrons also cause non linearity in the refractive index. Across the beam, plasma frequency modifies as $\omega_p^2 = 4\pi n e^2 / \gamma m_0$. Dielectric constant of plasma in relativistic regime takes the form $\varepsilon = 1 - \omega_p^2 / \gamma\omega^2$ where $\gamma = \left(1 + \alpha^2/2\right)^{1/2}$, $\alpha = eE/mc\omega$, E is the electric field of the laser pulse. Uneven variation of γ along wave front of the laser pulse causes the same effect as the Ponderomotive force does.

If the laser power P is greater than P_{cr} , ($P_{cr} = 17\,\omega_p^2 / \omega^2 GW$), then the relativistic mass variation of electron tend to self focus the laser beam.

Process of harmonic generation:

When laser of intensity more than 10^{18} W/cm^2 irradiates plasma its free electrons undergo non linear motion, as their quiver velocity approaches speed of light, the relativistic mass of electrons change. Equation of light wave contains nonlinear terms when relativistic motion of electrons is included, which contributes to generation of harmonics of incident light. Even when the electrons are non relativistic, such harmonics arise due to large oscillatory pressure of light wave is experienced by electrons at the interface. The main mechanism for second harmonic generation is the density gradient in plasma, electron density perturbs at plasma frequency. This density perturbation coupled with electron quiver motion gives rise to current at second harmonic frequency [14]. Near the critical layer resonant SHG takes place as laser mode converts itself into the plasma wave [15].

Magnetosonic wave

If a magnetic field is present in an ordinary gas, there are two additional restoring forces, the tension associated with magnetic field lines and the pressure associated with the energy density of the magnetic field. Thus, there are three magneto hydrodynamic (MHD) or hydro magnetic wave modes. The three modes have different propagation speeds, and are named as fast, slow and intermediate mode. The intermediate mode is sometimes called the Alfvén wave (AW), but some scientists refer to all three MHD modes as AWs. Some scientists give the name magneto sonic mode to the fast mode. Both types of waves can be launched by the turbulence of granulation and super granulation at the solar photosphere, and both types of waves can carry energy for some distance through the solar atmosphere before turning into shock waves that dissipate their energy as heat. A magneto sonic wave (also magneto acoustic wave) is a longitudinal wave of ions (and electrons) in a magnetized plasma propagating perpendicular to the stationary magnetic field. The phase velocity of the wave is given by

$$\frac{\omega^2}{k^2} = c^2 \frac{v_s^2 + v_A^2}{c^2 + v_A^2}$$

where v_s is the speed of the ion acoustic wave, v_A is the speed of the AW, and c is the speed of light in vacuum. In the limit of low magnetic field ($v_A \rightarrow 0$), the wave turns into an ordinary ion acoustic wave. In the limit of low temperature ($v_s \rightarrow 0$), the wave becomes a modified AW. Because the phase velocity of the magneto sonic mode is almost always larger than v_A, the magneto sonic wave is often called the "fast" hydro magnetic wave or fast wave. Both fast and slow magneto acoustic waves have been recently discovered in the solar corona, which created an observational foundation for the novel technique for the coronal plasma diagnostics, coronal seismology. Magneto sonic waves are sound waves that have been modified by the presence of a magnetic field, and AWs are similar to ultra low frequency (ULF) radio waves that have been modified by interaction with matter in the plasma. The chaotic behavior of the localized structures and steeper spectra (of power law k^{-S}) can be responsible for plasma heating and particle acceleration.

Turbulence:

Turbulence in fluids is a ubiquitous, fascinating, and complex natural phenomenon that is not yet fully understood. Due to the importance of electromagnetic forces and the typically violent environments, unraveling turbulence in high density, high temperature plasma is even a bigger challenge. The enormous difficulties in the observations on hot dense matter make the indirect inference of novel behavior of such matter. Mondala et.al.[16] observed the direct evidence of turbulence in giant magnetic fields created in an over dense, hot plasma by relativistic intensity(10^{18}W/cm^2) femtosecond laser pulses.

The results raise interest on the role of magnetic turbulence induced resistivity in the context of fast ignition of laser fusion, and the possibility of experimentally simulating such structures with respect to the sun and other stellar environments.

Critical density region:

The critical density region [17] using dielectric constant, plasma frequency, laser frequency etc is given as:

$\varepsilon = n^2 = 1-\omega_p^2/(\omega(\omega + i\nu))$

when $\omega_p = \omega$ (critical density)

$\omega_p < \omega$ (under dense)

$\omega_p > \omega$ (over dense)

$\omega_p = 4\pi Ne^2/m_e$

ε is the dielectric constant , ω_p is plasma density, ω is incident laser frequency, ν damping frequency(by electron- ion collision) N is electron density in plasma, m_e electron mass, e is charge on electron, n is refractive index of plasma.

When n^2 is positive the wave propagates through plasma, if n^2 is negative, light wave is attenuated. ω_p varies as $(N/m)^{1/2}$ Denser is plasma higher the ω_p , if mass of electron changes then ω_p will change.

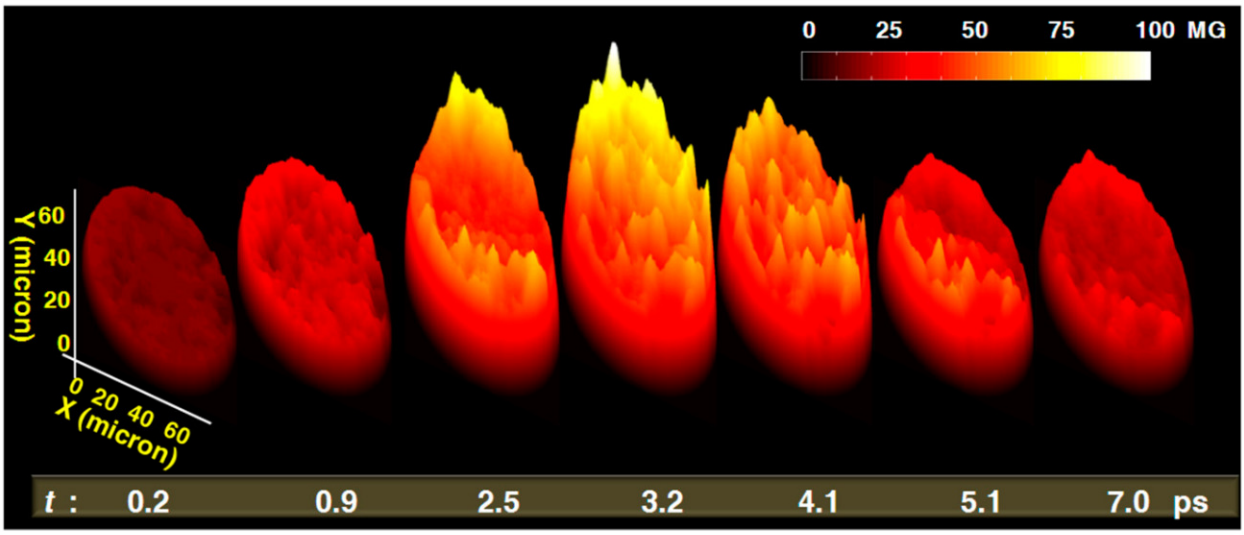
The temporal evolution of huge magnetic field is observed around the critical layer, which plays important role in electron transport [18]. Its important application is in hybrid confinement and fast ignition [19] schemes of laser fusion. Due to turbulence induced resistivity [20] fast electron [21] current and plasma return current get damped hence field is evolved. Such magnetic field is generated primarily near critical surface and so is the region of max laser absorption. Magnetic field up to giga gauss is predicted in the over dense region of solid target [22]. (Under dense plasma with $n_e=4x10^{19}cm^{-3}$ and near the critical surface $n_e \sim 10^{21}cm^{-3}$)

MOTIVATION

The propagation of ultra short (fs), high-power (TW) laser pulses, in plasma, opens a wide range of applications such as laser-plasma-based accelerators [23], self-channelling [24] harmonic generation, laser fusion schemes [22] and terahertz (THz) radiation sources. Traditional laser-based THz emitters like electro-optic crystals etc., when irradiated with high-power laser pulses, are subject to low conversion efficiencies and material breakdown. This problem is not encountered in plasma-based THz radiation sources [25], since plasma is impervious to material breakdown and has the potential of generating high-power THz. Recently many physical mechanisms have been reported for THz generation in plasma on interaction with a high-power laser pulse.

Laser-plasma interactions are affected by the presence of magnetic fields. When uniform magnetic field is embedded in the plasma, the self-focusing property of the laser beam can be observed. Also magnetization of the plasma leads to the possibility of second-harmonic generation. The effects of externally applied static magnetic fields have been reported [26] on wake excitation and non-linear evolution of laser pulses.

Sudipta Mondal et al [16] paper has been the main motivation for our research work, in this paper the evidence of turbulence in giant magnetic field in over dense and hot plasma by relativistic intensity (10^{18}W/cm^2) of femto second laser pulses has been presented. Turbulence is demonstrated by the spatial profile of magnetic field which shows randomness with certain well defined peaks at scales shorter than skin depth. The figure below shows complete dynamics of such magnetic field at critical surface of plasma.



Complete dynamics of spatio-temporal evolution of the intense laser induced magnetic field at the critical surface of the plasma measured with a 400-nm probe pulse

The largest terrestrially available magnetic fields are generated when an intense laser pulse (intensity above 10^{18}W/cm^2) irradiates a solid target [27]. We know that static electric and magnetic field in plasma enhances THz generation, the intensity of THz is proportional to magnetic field strength. One aspect is generation of THz and other turbulence in magnetic field created interest in further probing in to the part of turbulence.

Main aim of our research work is to study the evidence of turbulence in high magnetic field generated in the intense filamented region of magneto sonic wave having the THz frequency range. Here, MSW comes from the decay of high power laser (x mode) in very high magnetic field [28].

We will use MSW as a THz wave. The wave may be in the form of slow or fast magneto sonic wave. Filamentation process of MSW may be discussed under the different types of non linearities like Ponderomotive, collisional and relativistic filamentation.

In first problem we will study turbulence scaling near the critical density region by Ponderomotive filamentation of fast magneto sonic wave.

In second problem we will study the turbulence scaling near the critical density region by Ponderomotive /collisional filamentation of slow magneto sonic wave.

In third problem we will study of turbulent magnetic field spectra near critical density region by the relativistic filamentation of fast magneto sonic wave.

In the fourth problem of this research work, we will investigate the evidence of turbulence in magnetic field near critical density region by the relativistic filamentation of slow magneto sonic wave.

Research problem :

Turbulence in magnetic field at the critical density region by Ponderomotive and relativistic filamentation of fast and slow magneto sonic wave will be the focus of study during this research work. The steps will be taken as follows:

1: Study of turbulent magnetic field spectra near critical density region by the filamentation of fast magneto sonic wave

In this problem we will study the Ponderomotive filamentation of fast magneto sonic wave (FMSW) in the THz frequency range which is generated by the decay of high power laser (extraordinary mode). The waves get focused in the presence of Ponderomotive/collisional nonlinearity and at the focused position the intensity gets enhanced which leads to generation of very high magnetic field. The magnitude of self-generated giant magnetic field affects the laser plasma coupling. Therefore it is necessary to study the turbulent spectra of self generated magnetic field by using numerical techniques. Besides the study of the magnetic field intensity, we will investigate various diagnostics like phase portraits, surface plots, and also study the power spectrum. Outcome of these studies may be relevant to the laser fusion.

2: Turbulent magnetic field spectra near critical density region by the filamented slow magneto sonic wave

In this problem we will study the Ponderomotive filamentation of slow magneto sonic wave (SMSW) in the THz frequency range. The SMSW is generated by the interaction of high power laser (extraordinary mode) and UHW. The THz wave gets focused in the presence of Ponderomotive nonlinearity and at the focused position the intensity gets enhanced which leads to generation of very high magnetic field. The magnitude of self-generated magnetic field affects the laser plasma coupling. For this purpose the turbulent spectra of magnetic field will be studied by using numerical techniques. Besides the study of the magnetic field intensity, we will investigate various diagnostics like phase portraits, surface plots, and also study the power spectrum.

3: Study of turbulent magnetic field spectra near critical density region by the relativistic filamentation of fast magneto sonic wave

In this we will study relativistic filamentation of FMSW in the THz frequency range which is also generated by the decay of high power laser (X mode). The THz wave gets focused in the presence of relativistic nonlinearity and at the focused position the intensity gets enhanced which leads to generation of very high magnetic field. The magnitude of self-generated magnetic field affects the laser plasma coupling. Turbulent spectra of magnetic field have to be studied by using numerical techniques. Besides the study of the magnetic field intensity, we will investigate various diagnostics like phase portraits and surface plots.

4: Study of turbulent magnetic field spectra near critical density region by the relativistic filamentation of slow magneto sonic wave

In this we will study relativistic filamentation of SMSW in the THz frequency range which is also generated by the decay of high power laser (X mode). The SMSW gets focused in the presence of relativistic nonlinearity and at the focused position the intensity gets enhanced which leads to generation of very high magnetic field. The magnitude of self-generated magnetic field affects the laser plasma coupling. It is essential to study the power spectra of the self-generated magnetic field. We will also study the magnetic field intensity, phase portraits and surface plots by using numerical technique. These studies may have relevance in laser fusion.

Additional work

In the above research work the filamentation will be studied in paraxial regime. For the future work we can also study the effect of extended paraxial regime. Above work may be extended for transient state also. In transient state, magnetic field intensity and density may vary with time. Besides this we may also study THz generation by laser plasma interaction.

Methodology :

To carry out the research problems stated in previous part the numerical techniques like Euler method, Runge Kutta method or other suitable method mentioned ahead will be used, for doing so some approximations may be taken those are pointed below.

1) Paraxial ray approximation

The paraxial ray approximation is assumed when intense finite radius pulse propagates in plasma. The laser beam divergence angle is mostly considered to be very small and beam width is much greater than the wave length. Till the beam width remains larger than the radiation wavelength, the wave equation with paraxial approximation gives quite accurate picture of the beam near the axis throughout the propagation.

2) Extended-paraxial ray approximation

It becomes necessary to go beyond paraxial approximation when laser generates wide angle beams as semiconductor injection laser or solid state laser; in some cases the ring shaped distribution with hollow on the axis has been observed experimentally [29]. From initial Gaussian to the ring shape radial profile cannot be accounted by paraxial ray approximation, in which the eikonal is expanded till square of the radial coordinate (r). The dielectric constant and eikonal is expanded up to fourth power of radial distance, which modifies the dynamics of laser beam in the extended paraxial approximation. Compared to paraxial regime focusing is faster in extended paraxial regime. The off axial part generated by splitted profile of laser beam creates large difference in laser plasma coupling efficiency. Minimum power is found at the axis in the splitted profile of the laser beam. In extended paraxial regime the intensity distribution can be altered which affects uniformity of energy deposition of the laser beam hence affects laser beam propagation in THz generation.

3) Moment theory approach

In the laser plasma interaction the concept of moments was introduced by Vlasov et. al . The distribution function $f\left(x,\mathrm{v},t\right)$ of the plasma particles for velocity moments of various orders

was defined those could be related to some physical quantities. Ex. Zeroth order moment could be identified with number density

$$\int f\left(x,\mathrm{v},t\right)d\mathrm{v}=n$$

The first order by the mean velocity u multiplied by number density

$$\int \mathrm{v}f\left(x,\mathrm{v},t\right)d\mathrm{v}=nu$$

To study self focusing of laser beam in plasma Vlasov et. Al., then Lam et.al. [30] used the concept of moment theory using zero and second order spatial moments of intensity of laser beam as the base. With the help of the moments second order differential equation which show beam width parameter with the normalized distance of propagation can be derived.

4) <u>Variational method</u>

Variational approaches provide theoretical treatments and mathematical description of many physical phenomena. For performing Ponderomotive, eikonal or other averaging techniques variational principles provide a unified, compact framework. Integro differential equation or complicated partial differential equation may be replaced with quadrature, ordinary differential equations, linear equation, and ordinary function minimization for efficient approximation or numerical computation. This approximation may interpret, compute or provide insight more than the exact forms.

LITERATURE SURVEY

Sudipta Mondala et al [16] presented direct evidence of turbulence in giant magnetic fields in over dense, hot plasma due to relativistic intensity (10^{18}W/cm^2) of femto second laser pulses. They got magneto-optic polarigrams with micrometer spatial resolution at femto second time intervals. At scales shorter than skin depth the magnetic field spatial profile show randomness. Laser pulse create "hot" electrons with relativistic energy which generate forward current, thermal electrons induced in the target create "cold" return currents the interaction between them is simulated by two dimensional particle-in-cell, the results rise interest in the role of magnetic turbulence induced resistivity in the context of fast ignition of laser fusion.

M. Singh et al [28] reported efficiency of the order of ~ 1.4×10^{-2} with three wave parametric decay in which pump wave is laser beam (x-mode) decays in to upper hybrid wave (UHW) and THz wave in the magneto sonic mode. The appropriate expressions for THz wave amplitude and the coupling coefficients of the three wave interaction have been derived. Hence, the growth rate of this decay instability is also calculated. This paper also considers extra ordinary mode (x-mode) propagates perpendicular to background magnetic field.

R.P. SHARMA et al [31] investigated non linear interaction of circularly polarized high power laser beam in collision less magneto plasma with density ripple to excite Tera hertz (THz) radiation. With the appropriate phase matching conditions and by the beating of pump (laser) wave and density ripple electric field Ponderomotive force generates non linear current at difference frequency (difference between the laser and density ripple frequency). Circularly polarized beam propagating along the ambient magnetic field, filamentation is first investigated within paraxial ray approximation. The beam gets focused when the initial power of the laser beam is greater than its critical power. Analytical expressions for the beam width of the laser beam, electric vector of the THz wave have been obtained. For typical laser beam and plasma parameters with the incident laser power flux=10^{14} W/cm^2, laser beam radius (r_0)=40 μm, laser

frequency (ω_0)=10^{14} rad/s and plasma density (n_0)=3 × 10^{18} cm^{-3}, normalized ripple density amplitude (μ)=0.3, the produced THz emission can be at the level of Gigawatt in power.

Monika Singh et al [32] found the excitation of THz radiation which can be at the giga watt power level and calculated growth rate of decay instability which comes out to be $10^8 s^{-1}$, for laser plasma parameters with plasma density n_0=5.3x10^{18} cm^{-3}, pump wave frequency ω_0 =1.810x10^{14} rad/ s, normalized pump wave amplitude μ =0.4, and applied magnetic field B_0=105, 150, and 205 kG for T=1 KeV.The nonlinear interaction between the pump wave (UHW) and the extraordinary wave (laser) generates Ponderomotive force and hence nonlinear current is observed at the difference frequency. They considered extraordinary wave propagation perpendicular to the static magnetic field and polarized perpendicular to the same. They also derived expressions for the coupling coefficients for the three-wave interaction.

MUNTHER B. HASSAN et al [33] found that when the initial power of laser beam is greater than its critical power the relativistic change of electron mass causes self-focusing of laser beam. The self-focused laser beam couples with the density ripple to produce a nonlinear current which drives the THz radiation. The applied magnetic field enhances the nonlinear coupling efficiency. Appropriate expressions for the laser beam width parameter and the electric vector of the THz wave are evaluated. Theoretical and numerical simulations show that this THz source is capable of providing Giga watt range of power.

M. Singh et al [34] reported electron plasma (low density rippled) wave frequency (ω_1) = 1.2848 × 10^{14} rad/s, plasma density (n_0) = 5.025 × $10^{17}$$cm^{-3}$, normalized ripple density amplitude (μ)=0.1 and laser beam with the incident laser intensity ≈10^{14} W/cm^2, laser beam radius (r_0) = 50μm, laser frequency (ω_0) = 1.8848 × 10^{14}rad/s can generate THz at the power of 37GW range for laser beam propagation in extended paraxial region at ω_{ce}/ω_0 = 0.02. On the other hand for the same parameters in simple paraxial case its value comes out to be 1.7 GW range. Only with the appropriate phase matching, the frequency of the ripple and intense laser beam the difference frequency can be brought in the THz range. Self focusing (filamentation) of a

circularly polarized beam propagating along the direction of static magnetic field in plasma is investigated within extended-paraxial ray approximation. The THz radiations driven by the resulting localized beam coupled with the pre-existing density ripple produce nonlinear current.

Monika Singh et al [35] reported efficiency in terahertz (THz) generation of the order of ~ 8×10^{-3} by the cross-focusing of two collinear Gaussian lasers. The lasers exert Ponderomotive force which imparts an oscillatory velocity to the electrons. These oscillations couple with density ripple under phase matching condition generates strong transient transverse current which causes THz radiation as the resonant excitation with frequency of the order of plasma frequency.

Rabea Q. Nafil [36] reported with the increase in the static electric field from 10 KV cm^{-1} to 50 KV cm^{-1} the efficiency of THz wave increases over 24.5 times, hence the nonlinear coupling of two high-power laser beams in plasmas in the presence of a transverse, static electric field is an efficient method to produce THz radiation at the GW level efficiency of the order of ~10^{-4} was reported. The relativistic variation of electron mass in the presence of two high-power laser beams is responsible for producing such THz radiation

G Ravindra Kumar [37] reported spatio-temporal evolution of the magnetic fields at target front and rear, ultrafast dynamics of the plasma critical surface. Interesting efforts are being made to search and understand newer ways of coupling light to dense plasma, particle emissions and their dependence on various laser and target parameters, hot electron transport, giant magnetic field generation and similar plasma processes. Pump-probe experiments with relativistic intensity 30 fs, 10 Hz, 800 nm Ti: Sapphire laser pulses are considered. Tabletop terawatt, femtosecond lasers offer flexibility, robustness and repeatability hence enable faster progress in high energy density science.

M. Borghesi et al [38] measured the spatial, temporal and spontaneous megagauss magnetic fields using Faraday rotation with picosecond resolution, when solid target was irradiated by

picosecond pulse above $5x10^{18}$ W/cm^2 A high density plasma jet has been observed by interferometry and optical emission along with the magnetic fields.The first direct comparison between experimental data and magnetohydrodynamic (MHD) simulations in laser produced plasmas was observed by running 2D MHD code for the conditions of the experiment. The main features demonstrated that the jet is formed due to pinching by the magnetic fields.

R. Dragila [39] showed that in laser produced plasma experiment axial magnetic field can be generated by the action of turbulent dynamo in under dense plasma in presence of ion acoustic turbulence. The original toroidal magnetic field is enhanced by this axial magnetic field, for example by crossed gradients of electron density and temperature or by a beam of fast electrons. Such a beam can drive ion acoustic instabilities that give rise to ion acoustic turbulence that is necessary for turbulent dynamo to operate.

Pallavi Jha et al [40] presented analytical study of terahertz (THz) radiation generation by propagation of short laser pulses in homogeneous under dense magnetized plasma, in the mildly relativistic regime in which wake fields are produced. Uniform magnetic field is applied perpendicular to both electric vector and direction of propagation of the laser field. Behind and within the laser pulse electric and magnetic wake fields are generated by a perturbative technique for weak applied magnetic fields. On–axis THz radiation is generated by coupling slow plasma electron velocity with the transverse magnetic field, quasi static approximation (QSA) is used for this. For typical laser and plasma parameters, they reported THz field intensity of 93.84GW/cm^2 is generated behind and 52.7GW/cm^2 inside the laser pulse. The peak amplitude within the laser pulse is about 34% less than the amplitude behind the laser pulse.

Joseph Peñano et al [41] investigated third order susceptibility due to nonlinear coupling of the fundamental and the frequency doubled laser pulses in plasma, it has a time dependent characteristic of the laser pulse durations. Terahertz so generated depends on the relative polarizations of the lasers, and (τ_L) the laser pulse duration. In absence of electron collisions the relativistic term cancels Ponderomotive force term in such susceptibility. Hence collisions play

important role in THz generation and its field amplitude depends on the intensity of fundamental and second harmonic laser pulses. They reported, with the duration comparable to that of the drive laser pulses, the emitted terahertz field amplitude is on the order of tens of kilovolts/cm.

P. Sprangle et al [42] analyzed sub-THz electromagnetic pulse (EMP) generation due to interaction of intense ultra short laser pulses with air/dielectric surface. They found conversion efficiencies are on the order of 10^{-9} , peak EMP power of 8 W, with plasma density of n_e~10^{16} cm^{-3}, the electron collision frequency is ν_e~$5x10^{12}$ sec^{-1} (for *Te*=1 eV), EMP intensities on the order of MW/cm^2 can be simulated from the interaction of a laser pulse with a dielectric medium. In their model they considered collective effects of diffraction, Kerr focusing, plasma defocusing, and energy depletion due to electron collisions, ionization and recombination processes. Laser pulse partially ionizes the medium, forms a plasma filament, the Ponderomotive forces drive plasma currents which are the source of the EMP. EMP energy is radiative only for transient laser pulse propagation.

A S. Sandhu et al [43] demonstrated the temporal evolution of ultra short with 6 ps, multi mega gauss of 27 MG magnetic pulses are generated near the critical layer, due to the interaction of intense laser pulse of 10^{16} Wcm $^{-2}$, 100 fs with a solid target. They explained results with Particle-in-cell simulations and phenomenological modeling. They observed hot electron currents penetrating the bulk plasma rapidly dampen plasma shielding currents.

S. Tzortzakis et al [44] reported by use of two heterodyne detectors at 94±1 GHz and 118 ±1 GHz detected sub THz emitted by filamentary structure from an intense IR femtosecond laser pulse which was found perpendicular to the laser propagation axis. Such emission takes place from 1-m string in the atmosphere and they got the evidence of constructive interference between two separate strings.

Yukhimuk et al [45] found instability growth rate with non linear dispersion relation describing three-wave interaction i.e. Alfven waves with magneto sonic and ion-acoustic waves on the basis of two-fluid magnetohydrodynamics. In consequence of rapid dissipation, these waves can effectively heat the coronal plasma. Nonlinear parametric processes studied in the paper could take place in the solar coronal loops, solar magnetosphere and the Earth's magnetosphere where plasma parameter is small. Typical parameters for such loop are, length 2 $x10^9$ to $5x10^9$ cm, n = $0.5x10^{10}$ to 10^{10} cm^{-3}, B=100 to 500 G, T =$4x10^6$ K, $\omega_{pe}/\omega_{Be} \approx 10$, $\mu_e \approx 1$, $\omega_1 \approx 10^{-1}\ \omega_{Bi}$ substituting these values of the plasma parameter and kinetic Alfven wave (KAW) intensity $W \approx 10^{-5}$ to10^{-6} they found time instability $\tau = \gamma^{-1} \approx 0.01$ c.

Benjamin D. G. Chandran [46] used weak-turbulence theory to investigate interactions among Alfve´n waves and fast and slow magneto sonic waves in collision less low-β plasmas. From the equations of magneto hydrodynamics, the wave kinetic equations are derived, to model collision less damping extra terms were added. The variety of non linear processes as energy transfer between wave types, parallel and perpendicular energy cascade,‘‘phase mixing’’ and the generation of backscattered Alfve´n waves are quantitatively described using these equations.

V. A. Svidzinski et al [47] performed electromagnetic particle in cell simulations at ion cyclotron frequency range in two-dimensional plane geometry for nonlinear waves propagation and interaction in magnetized plasma. Nonlinear dynamics of spectrum of fast magneto sonic wave modes with wave numbers perpendicular and parallel to the uniform magnetic field launched into plasma was analyzed. According to the results the wave magnetic energy spectrum cascades to smaller scales. The cascade is basically isotropic at the low frequency in the magneto hydrodynamic regime, the cascade exhibits strong anisotropy at high frequency kinetic regime, in direction perpendicular to the equilibrium magnetic field it extends to much smaller scales. After a few ion cyclotron periods only the shape of the cascade is established, most of the energy in the cascade stays in the fast wave oscillations. The main dissipation channel is considered to be collision less damping of electrons.

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